Report Documentation Page

Report Documentation Page	Form Approved OMB No. 0704-0188

1. REPORT DATE **01 JUN 2013**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Functional Rehabilitation With a Foot Plate Modification for Circular External Fixation**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Blair J. A., Owens J. G., Saucedo J., Hsu J. R.,**		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **United States Army Institute of Surgical Research, JBSA Fort Sam Houston, TX**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**9**	

Article

AMERICAN ORTHOPAEDIC FOOT & ANKLE SOCIETY.

Foot & Ankle International
XX(X) 1–8

Reprints and permissions:
sagepub.com/journalsPermissions.nav
DOI: 10.1177/1071100713483975
fai.sagepub.com

Functional Rehabilitation With a Foot Plate Modification for Circular External Fixation

James A. Blair, MD[1], Johnny G. Owens, MPT[2], Joey Saucedo[1], Joseph R. Hsu, MD[3], and Skeletal Trauma Research Consortium (STReC)[1,4]

Abstract

Background: Customized foot plates attached to the foot ring of an ankle-spanning circular external fixator present a unique opportunity for patients undergoing complex lower-extremity limb salvage to participate in highly advanced weight-bearing physical therapy. The purpose of this study was to identify the rehabilitation capabilities afforded by this external fixator modification.

Methods: Surgical logs and radiographs were reviewed to identify all lower-extremity limb salvage patients from February 2008 to December 2010 treated with an ankle-spanning circular external fixator and a customized foot plate treated by the same orthopedic surgeon and enrolled in our institution's Return To Run clinical pathway. Medical records were reviewed to identify a series of exercises that each patient was able to perform.

Results: Eleven patients were identified. All patients were treated by the same physical therapist. All 11 patients were able to bear full weight on their foot plates and perform regular and split squats. Six of 11 patients were able to ambulate unassisted, and 5 patients required a cane. All 11 patients could navigate stairs and use an elliptical and stair-stepping machine. Six of 11 patients could perform single-leg hack squats. Eight of 11 patients were able to perform double-leg shuttle jumps, although only 5 of 11 patients could perform single-leg shuttle jumps. Five of 11 patients were able to perform a single-leg balance. Only 1 patient was able to run on the foot plate.

Conclusions: Patients undergoing lower-extremity limb salvage with an ankle-spanning circular external fixator and a customized foot plate were able to participate in highly advanced weight-bearing physical therapy exercises during the osseous and soft-tissue healing process.

Level of Evidence: Level IV, retrospective case series.

Keywords: Taylor spatial frame, Ilizarov, foot plate, limb salvage, Return To Run

Throughout the United States' current overseas conflicts in Iraq and Afghanistan, wounded service members are sustaining devastating injuries, mostly due to explosive mechanisms.[10] Recent advances in battlefield medicine have increased the survival rate of these injuries[9] but leave the wounded service members with highly complex extremity injuries. While many of these injuries go on to amputation, a large number have been treated with various limb salvage techniques, most notably with circular external fixation.

While ankle-spanning circular external fixation is a treatment option for distal tibia fractures as well as for maintaining a neutral foot in the setting of a neurologic injury,[3,5,6,16,19] multiple studies[3,5] have suggested that weight bearing in an ankle-spanning circular external fixator must be delayed until the patient has radiographic evidence of healing. In the past, many limb salvage patients at our institution witnessed their amputee counterparts achieve seemingly higher levels of function at a faster pace. These patients demanded a better way to rehabilitate while undergoing osseous and soft-tissue healing. Thus, in partnership with our institution's physical therapy department and the Center For the Intrepid, the Return To Run clinical pathway (RTR)[11] was developed.

[1]Department of Orthopaedics and Rehabilitation, Brooke Army Medical Center, Fort Sam Houston, TX, USA
[2]Limb Salvage Rehabilitation, Center For the Intrepid, Brooke Army Medical Center, Fort Sam Houston, TX, USA
[3]Orthopaedic Trauma, Carolinas Medical Center, Charlotte, NC, USA
[4]United States Army Institute of Surgical Research, Fort Sam Houston, TX, USA

Corresponding Author:
James A. Blair, MD, Department of Orthopaedics and Rehabilitation, Brooke Army Medical Center, 3851 Roger Brooke Drive, Fort Sam Houston, TX 78234, USA.
Email: james.blair@amedd.army.mil

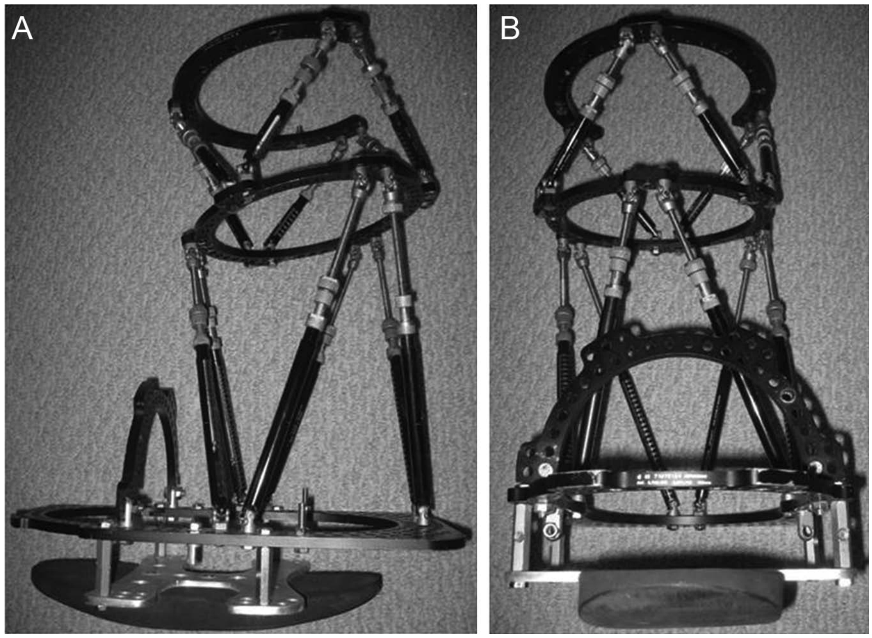

Figure 1. A lateral (A) and anterior (B) view of a Taylor spatial frame with the described foot plate modification attached.

The RTR involves intense rehabilitation both in and out of circular external fixation. While in circular external fixation, we employ a customized footplate and allow our patients undergoing limb salvage with an ankle-spanning circular external fixator to bear weight immediately (Figure 1). Lower-extremity strength training in the form of squats and lunges begins as soon as the patient is able to tolerate weight bearing on the injured extremity. Plyometric exercises are introduced once the patient is able to leg press or squat 80% of his body weight. After plyometrics are tolerated without an increase in pain while in circular external fixation, agility training commences in the form of footwork, cutting, and deceleration drills.

The purpose of this study was to investigate the functional capabilities in the initial cohort of consecutive patients undergoing lower-extremity limb salvage in an ankle-spanning circular external fixator using the previously described foot plate attachment and participating in the RTR. To our knowledge, the rehabilitation capacity of these patients with this type of circular external fixation in place while participating in intense physical therapy has yet to be described in the literature.

Methods

A retrospective chart analysis identified 11 consecutive active-duty military patients undergoing lower-extremity limb salvage with an ankle-spanning Taylor spatial frame (TSF) and our foot plate modification from February 2008 to May 2010. February 2008 was chosen as the start point for this study as it marked our first use of the described foot plate modification. All 11 patients were treated by the same orthopedic surgeon and physical therapist using the RTR.[11] Only 1 patient (patient 7) was initially treated with a hinged TSF that spanned the knee. The knee-spanning portion of this patient's TSF was removed the same day the ankle-spanning TSF with the foot plate modification was applied. Outpatient, inpatient, and physical therapy records were reviewed to identify specific rehabilitation exercises each patient was able to perform. The exercises investigated specifically included weight bearing, ambulation, squats, split squats, single-leg hack squats, double- and single-leg shuttle jumps, elliptical and stair-stepping machine use, single-leg balance, and running.

Our foot plate modification (Figure 2) was constructed with an aluminum H-plate that was approximately 6-mm thick, which was bolted to the circular external fixator frame. A carbon fiber footplate was glued to a piece of ¼-inch orthopedic crepe. The crepe and the carbon fiber footplate were then riveted to the H-plate with 3 copper rivets centered on the carbon footplate. The crepe side faced the surface of the H-plate with the carbon fiber exposed at the bottom. A customized rocker bottom crepe sole was glued to the bottom of the assembly. Once finishing work was complete, the rocker bottom sole was fitted with a nonslip soling cap.

For our study purposes, we defined a squat as being able to achieve a crouched position with both knees bent to 90 degrees with the back straight from a standing position (Figure 3). Split squats require the patient to take a half step forward on the affected limb and allow the contralateral knee to flex toward

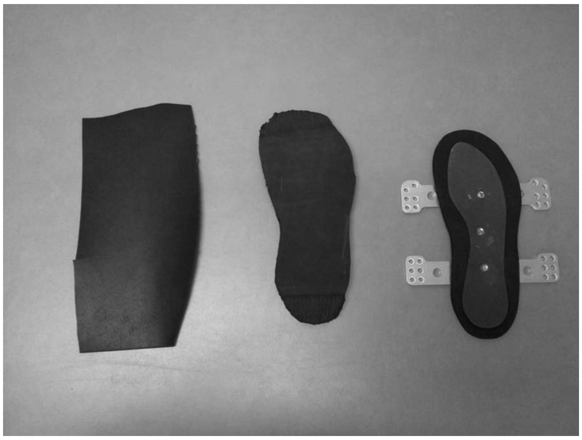

Figure 2. From left to right: rubber rocker bottom sole tread, rocker bottom sole, H-plate with a riveted carbon fiber shank attached.

Figure 3. A lower-extremity limb salvage patient performing a modified split squat.

the floor while maintaining the front knee and ankle in a straight vertical plane. Single-leg hack squats and shuttle jumps were performed on a Shuttle MVP Pro supine squat machine (Shuttle Systems Inc, Glacier, WA; Figure 4). Single-leg hack squats were performed with the patient lying supine in the squat machine and allowing the affected hip and knee to flex to 90 degrees from neutral and then return to the starting position. Double- and single-leg shuttle jumps required the

Figure 4. Shuttle MVP Pro supine squat machine. Photo courtesy of Shuttle Systems Inc (Glacier, WA).

Figure 5. A lower-extremity limb salvage patient performing a single-leg shuttle jump.

patient to perform a plyometric jump while lying supine in the squat machine. The starting position was with the hips and knees flexed at 90 degrees. The patient then performed simultaneous isometric knee and hip extension, allowing the foot to come off the base plate of the squat machine (a modified jump). The patient jumped and landed with both lower extremities during a double-leg shuttle jump but only the affected extremity in a single-leg shuttle jump (Figure 5). Finally, a patient was given credit for a single-leg balance if he could maintain balance unassisted on his foot plate for 10 seconds.

All 11 patients were men, with an average age of 27.6 years (range, 19-45 years). The average length of foot plate use was 245 days (range, 70-518 days). The mechanism of injury for 4 patients was a blast injury, either by an improvised explosive device or rocket-propelled grenade. Four patients sustained gunshot wounds, 2 patients were involved in a motorcycle crash, and 1 patient was involved in a rollover motor vehicle accident. Patient demographic data can be found in Table 1. A description of the cohort's osseous injuries may be found in Table 2. One patient underwent bilateral lower-extremity limb salvage in TSFs;

Table 1. Patient demographics.

Patient	Gender	Age, y	MOI	Length of Foot Plate Utilization, d
1	M	24	MCC	87
2	M	20	IED	226
3	M	30	GSW	226
4	M	29	MVA	83
5	M	29	GSW	334
6	M	20	RPG	384
7	M	26	RPG	175
8	M	43	GSW	518
9	M	19	GSW	177
10	M	45	MCC	415
11	M	21	IED	70

Abbreviations: GSW, gunshot wound; IED, improvised explosive device; MCC, motorcycle collision; MOI, mechanism of injury; RPG, rocket-propelled grenade.

Table 2. Patient injuries.[a].

Patient	Osseous Injury
1	G/A IIIB tibial shaft fracture, closed fracture/dislocation, multiple MT fractures
2	G/A IIIB tibial shaft fracture
3	G/A IIIC tibial shaft fracture
4	G/A IIIB distal fibula fracture
5	Closed tibial pilon fracture
6	G/A IIIB tibial shaft fracture
7	G/A IIIB tibial plateau fracture, IIIB tibial shaft fracture
8	Closed tibial pilon fracture, talus fracture
9	G/A IIIB tibial pilon fracture
10	G/A IIIB tibial shaft fracture
11	G/A IIIB tibial shaft fracture, calcaneus fracture

Abbreviations: G/A, Gustilo-Anderson; MT, metatarsal.
[a]Multiple injuries refer to the same extremity.

however, only 1 circular frame had a foot plate attached. By December 2010, all 11 patients had undergone removal of their circular external fixator. All fractures were united at the time of TSF removal.

Results

A graphical representation of patient achievements can be found in Table 3. At the conclusion of the study period, all 11 patients were able to bear full weight on their foot plate. More than half of the patients (6 of 11) were able to ambulate without the need for assistive devices, while the remaining 5 patients required the use of a cane. Every patient was able to ascend and descend stairs. Only 5 of 11 patients could perform a single-leg balance on their affected extremity. Only 1 patient was able to truly run in his circular external fixator.

There were multiple complications documented that hindered the rehabilitation for a few of the patients (Table 4). Four patients developed knee contractures of their affected limb during the healing process. Of these 4 patients, 1 patient had initially sustained a direct injury to his knee requiring a knee-spanning TSF prior to his ankle-spanning TSF with foot plate modification application, while another patient underwent a marked proximal tibial bone transport. The third patient developed a knee contracture secondary to full-thickness 5% total body surface area burns sustained to his affected limb. The fourth patient developed a knee contracture from an unknown cause. All 4 knee contractures resolved prior to foot plate removal after emphasized knee extension therapy. Patient 8 also broke his circular foot ring. Five patients had significant concomitant injuries that slowed their rehabilitation, including a lumbar spine fracture without neurologic injury (1 patient), burns not to the lower extremities (1 patient), and bilateral lower-extremity injuries (3 patients). Of the 3 patients with bilateral lower-extremity injuries, only 1 patient had bilateral TSFs, of which only 1 was ankle spanning. Five patients underwent additional surgical procedures after the frame was removed (Table 4). Two patients (patients 2 and 5) underwent a delayed elective transtibial amputation for refractory nerve pain. Only 1 patient (patient 8) required a repeat circular external fixator application after the initial removal, which was to correct an intolerable residual limb length discrepancy.

Table 5 provides a description of each patient's final outcome as of December 2011. Seven of the 9 patients with salvaged limbs were able to run with appropriate bracing.[14]

Discussion

This study assessed the rehabilitation capacity of patients who are actively undergoing lower-extremity limb salvage in a TSF over a 34-month period of time using a novel rehabilitation protocol. The foot plate modification described has been the crucial element that has allowed patients with ankle-spanning circular fixation to participate in the RTR. Prior to the inception of this modification, limb salvage patients had to wait until their circular fixation was revised to the tibia only or until the entire frame was removed, which would result in an absence of weight-bearing physical therapy for more than a year in some instances. We designed multiple foot plate modifications, and the one we currently use has been the most durable and preferable to our patients. As detailed above, the RTR was created, in part, because of patient request for more core and lower-extremity strengthening and conditioning while undergoing osseous and soft-tissue healing in circular external fixation. We believed this pathway would help propel a patient's rehabilitation once the external fixator was removed and allow the patient to return to running and sport participation sooner.[11,14,15] A number of studies have

Table 3. Patient rehabilitation.[a].

Patient	Weight Bear	Unassisted Ambulation	Ambulation With Cane	Squat	Split Squat	Single-leg Hack Squat	Double-leg Shuttle Jump	Single-leg Shuttle Jump	Elliptical	Stair-Stepping Machine	Single-Leg Balance	Run
1	X	X		X	X	X	X		X	X		
2	X	X		X	X				X	X		
3	X		X	X	X		X		X	X		
4	X	X		X	X	X	X	X	X	X	X	
5	X		X	X	X				X	X		
6	X	X		X	X	X	X		X	X		X
7	X		X	X	X	X	X	X	X	X	X	
8	X		X	X	X		X		X	X	X	
9	X	X		X	X				X	X		
10	X		X	X	X	X	X	X	X	X	X	
11	X	X		X	X	X	X	X	X	X	X	

[a]An “X” denotes that the patient is able to perform the exercise.

Table 4. In-frame complications and additional surgical procedures.

Patient	Complication (in Frame)	Additional Procedures After Frame Removal
2	Knee flexion contracture due to burns	Transtibial amputation due to refractory pain
5		Transtibial amputation
6	Knee traumatic osteoarthritis and flexion contracture	
7	Knee flexion contracture after massive proximal tibial bone transport	
8	Knee flexion contracture	Circular external fixator reapplication for residual limb length discrepancy
10	Broken foot ring[a] (Figure 6)	Operative debridement and irrigation due to osteomyelitis at a former pin tract

[a]Patient required a revision Taylor spatial frame application.

Table 5. Final rehabilitation outcomes.

Patient	Final Functional Outcome
1	Back on active duty in the Army, able to run short distances in an IDEO
2	Underwent a transtibial amputation for refractory nerve pain, able to run in prosthesis
3	Back on active duty in the Army, able to run in an IDEO
4	Returned to full active duty in the Army, able to run and skydive in an IDEO, redeployed overseas
5	Able to ambulate with a cane in an IDEO, underwent an elective transtibial amputation
6	Able to run in an IDEO, separated from the Army, full-time college student
7	Able to run in an IDEO, released without limitations, participated in a mini-triathalon
8	Able to walk without assistive devices in an IDEO, unable to run secondary to pain
9	Able to walk without assistive devices in an IDEO, unable to run, separated from the Army
10	Able to run in an IDEO, completed a 150-mile cycling race at an Olympic training facility
11	Able to ambulate without assistive devices, unable to run secondary to back pain, separated from the Army

Abbreviation: IDEO, intrepid dynamic extraskeletal orthosis.[14]

measured a functional assessment after treatment in a TSF,[2,4,8,12,13,17,18] either after infectious or traumatic conditions. However, this study differs significantly in that our patients are still in a TSF and actively undergoing osseous and soft-tissue healing.

Recent literature has documented the initial successes of the RTR. Participation in the RTR has allowed service members sustaining limb-threatening injuries in the current conflicts in Iraq and Afghanistan to return to many athletic activities, including running, cycling, basketball, and softball.[11]

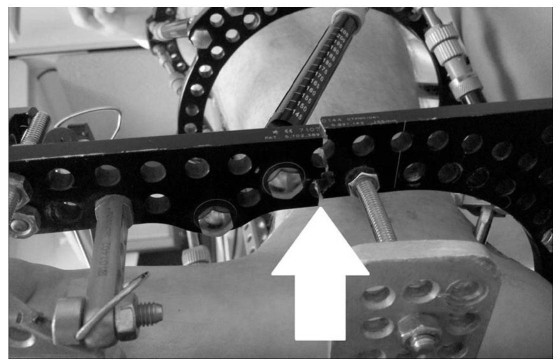

Figure 6. The white arrow demonstrates a break in the circular distal foot ring.

Similarly, injured service members who have participated in the pathway have experienced increased voluntary deployment rates.[15] Current ongoing research is investigating seemingly increased overall return-to-duty rates in service members participating in the RTR and using a novel custom orthosis. This may ultimately translate into higher return-to-work rates in the civilian population.

Multiple studies suggest there should be a delay in weight bearing when treating a patient with an ankle-spanning circular external fixator.[3,5,12] In Kapoor and colleagues' study[5] of 17 patients being treated with an ankle-spanning Ilizarov fixator for high-energy pilon fractures, weight bearing was delayed for an average of 13.1 weeks. Similarly, in the description by Bozkurt et al[3] of a closed reduction and circular external fixator placement for closed pilon fractures, the authors detailed a delay in weight bearing for 5 weeks. While others[12] suggest delaying weight bearing until wound healing has occurred, the presented work is comparable to work done by Bacon et al[1] in their study of 14 patients with comminuted tibial pilon fractures treated with an ankle-spanning Ilizarov fixator in which they

allowed patients to bear full weight in the immediate postoperative period with a resulting time to fracture union of 24.5 weeks. It is difficult to determine whether advanced rehabilitation in a circular external fixator promotes or prolongs healing as there was no control cohort in this preliminary data set. The case with foot ring breakage required a return trip to the operating room for a frame revision, although this did not seem to impede rehabilitation progress. The trend that the less severe injuries predictably took less time to heal, and vice versa, allows us to theorize that this form of aggressive rehabilitation likely does not prohibit osseous and soft-tissue healing.

The current study helps demonstrate that not only can immediate postoperative weight bearing occur in patients treated with ankle-spanning circular external fixators, but aggressive weight-bearing rehabilitation can be tolerated in motivated patients. The broken TSF components (Figure 6) suggest that we are able to rehabilitate these patients to the point of fatigue failure of the metal and concomitant components of the circular fixator. We consider this to be a proof of concept that high-energy lower-extremity limb salvage patients can undergo intense weight-bearing rehabilitation while undergoing bone transport, bone docking, and soft-tissue healing. Fixator breakage may be a future manufacturing and construction consideration as more high-intensity limb salvage patients demand higher performance out of their circular external fixators. The authors do not believe that this aggressive rehabilitation decreased the time to osseous union while in circular external fixation, although it is believed that it did not delay union either. The general consensus of our patients was that aggressive rehabilitation while in their frames helped to accelerate their rehabilitation once the external fixator was removed.

The retrospective nature of this study is a limitation, and the small sample size limits the ability to make statistical interpretations. However, our most significant limitation in this study is the relatively homogenous patient population, although with differing injuries. Because of the nature of many military patients, these patients are, in essence, moderate to high performance athletes. They are in an ideal social setting with an equal and essentially unlimited access to very specialized health care, world-class rehabilitation, and social work support. This is in stark contrast to the average high-energy lower-extremity trauma patient as described by MacKenzie et al.[7] A wide range in the time each patient had a foot plate may alter what the cohort of patients could do as a whole; however, 2 of our highest-performing patients were on either end of the time range spectrum. Unfortunately, an injury-matched cohort who had not participated in aggressive rehabilitation while in circular external fixation is not available for comparison of rehabilitation effectiveness and osseous healing rates. The use of a validated outcome measure rather than dichotomous data may have improved the quality of the data interpretation. Major strengths of the study include consecutive patient enrollment and use of the same clinical device and rehabilitation pathway.

In conclusion, we have determined that despite a wide variety of devastating injuries, patients undergoing lower-extremity limb salvage with a foot plate modification attached to an ankle-spanning circular external fixator were able to participate in highly advanced physical therapy and had increased functional independence. Aggressive lower-extremity physical therapy could be performed while in an ankle-spanning circular external fixator. Continued investigation of these patients may show a faster return to preinjury activities.

Disclaimer

The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense. This study was conducted under a protocol reviewed and approved by the US Army Medical Research and Materiel Command Institutional Review Board and in accordance with the approved protocol. All patients have given their expressed written consent to be photographed for the purpose of this article.

Although none of the authors have received or will receive benefits for personal or professional use from a commercial party related directly or indirectly to the subject of this article, benefits have been or will be received but are directed solely to a research fund, foundation, educational institution, or other nonprofit organization with which one author (J.R.H.) is associated.

No funds were received in support of this study.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors declared receipt of the following financial support for the research, authorship, and/or publication of this article: This study was funded by the United States Army Institute of Surgical Research and the Combat Casualty Care Research Program.

References

1. Bacon S, Smith WR, Morgan SJ, et al. A retrospective analysis of comminuted intra-articular fractures of the tibial plafond: open reduction and internal fixation versus external Ilizarov fixation. *Injury*. 2008;39:196-202.
2. Barker KL, Lamb SE, Simpson AHRW. Functional recovery in patients with nonunion treated with the Ilizarov technique. *J Bone Joint Surg Br*. 2004;86-B:81-85.
3. Bozkurt M, Ocguder DA, Ugurlu M, Kalkan T. Tibial pilon fracture repair using Ilizarov external fixation, capsuloligamentotaxis, and early rehabilitation of the ankle. *J Foot Ankle Surg*. 2008;47(4):302-306.
4. Giotakis N, Panchani SK, Narayan B, et al. Segmental fractures of the tibia treated by circular external fixation. *J Bone Joint Surg Br*. 2010;92(5):687-692.

5. Kapoor SK, Kataria H, Patra SR, Boruah T. Capsuloligamentous and definitive fixation by an ankle-spanning Ilizarov fixator in high-energy pilon fractures. *J Bone Joint Surg Br*. 2010;92-B:1100-1106.
6. Kapukaya A, Subasi M, Arslan H. Management of comminuted closed tibial plafond fractures using circular external fixators. *Acta Orthop Belg*. 2005;71(5):582-589.
7. MacKenzie EJ, Bosse MJ, Kellam JF, et al. Characterization of patients with high-energy lower extremity trauma. *J Orthop Trauma*. 2000;14(7):455-466.
8. McKee MD, Yoo D, Schemitsch EH. Health status after Ilizarov reconstruction of post-traumatic lower-limb deformity. *J Bone Joint Surg Br*. 1998;80-B:360-364.
9. Owens BD, Kragh JF Jr, Macaitis J, et al. Characterization of extremity wounds in Operation Iraqi Freedom and Operation Enduring Freedom. *J Orthop Trauma*. 2007;21(4):254-257.
10. Owens BD, Kragh JF Jr, Wencke JC, et al. Combat wounds in operation Iraqi Freedom and Operation Enduring Freedom. *J Trauma*. 2008;64(2):295-299.
11. Owens JG, Blair JA, Patzkowski JC, et al. Return to running and sports participation after limb salvage. *J Trauma*. 2011;71(1 suppl):S120-S124.
12. Öztürkmen Y, Karamehmetoğlu M, Karadeniz H, et al. Acute treatment of segmental tibial fractures with the Ilizarov method. *Injury*. 2009;40:321-326.
13. Paley D, Maar DC. Ilizarov bone transport treatment for tibial defects. *J Orthop Trauma*. 2000;14(2):76-85.
14. Patzkowski JC, Blanck RV, Owens JG, et al. Can an ankle-foot orthosis change hearts and minds? *J Surg Orthop Adv*. 2011;20(1):8-18.
15. Patzkowski JC, Owens JG, Blanck RV, et al. Deployment after limb salvage for high-energy lower-extremity trauma. *J Trauma Acute Surg*. 2012;73(2 suppl 1):S112-S115.
16. Ristiniemi J, Luukinen P, Ohtonen P. Surgical treatment of extra-articular or simple intra-articular distal tibial fractures: external fixation versus intramedullary nailing. *J Orthop Trauma*. 2011;25:101-105.
17. Rozbruch SR, Pugsley JS, Fragomen AT, et al. Repair of tibial nonunions and bone defects with the Taylor spatial frame. *J Orthop Trauma*. 2008;22(2):88-95.
18. Rozbruch SR, Weitzman AM, Watson JT, et al. Simultaneous treatment of tibial bone and soft-tissue defects with the Ilizarov method. *J Orthop Trauma*. 2006;20(3):197-205.
19. Sirkin M, Sanders R, DiPasquale T, Herscovici D Jr. A staged protocol for soft tissue management in the treatment of complex pilon fractures. *J Orthop Trauma*. 2004;18 (8 suppl): 532-538.